COMPARISONS OF THE MG II INDEX PRODUCTS FROM THE NOAA-9 AND NOAA-11 SBUV/2 INSTRUMENTS

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ABSTRACT. The Mg II index is a proxy indicator of solar UV activity which is produced from measurements of the chromospheric Mg II absorption line at 280 nm. Mg II index data sets have been derived from the NOAA-9 and NOAA-11 SBUV/2 irradiance data sets using both discrete scan measurements about the Mg II line and continuous scan (sweep) measurements over the UV spectrum from 160-400 nm. This paper will discuss the rationale behind the creation of the different Mg II index products, and make a quantitative assessment of the differences between these products. Recommendations for future use of the Mg II index will also be presented.

INTRODUCTION

Solar ultraviolet variability in the 200-350 nm wavelength region is the primary driver for ozone variations in the upper stratosphere. In order to fully understand the contribution of solar activity to ozone variations, knowledge of long-term solar change to an accuracy of 1% is required. This goal has proven to be difficult to achieve with absolute irradiance measurements because of the significant changes in instrument response exhibited by satellite instruments (*e.g.* Schlesinger and Cebula, 1992; Cebula and DeLand, 1992; Brueckner *et al.*, 1993). In lieu of direct measurements of solar UV variability, proxy indexes are used to represent these changes. One such index is the Mg II index, first derived by Heath and Schlesinger (1986) from Nimbus-7 SBUV measurements using the Mg II absorption line at 280 nm. The irradiance in the core of the unresolved Mg II doublet is representative of chromospheric activity, while the irradiance in the wings of the line approximates the local continuum. Using the ratio of these quantities removes most instrumental change effects, and provides a good indicator of solar UV variability on both rotational and solar cycle time scales (Heath and Schlesinger, 1986). Scale factors have also been derived to estimate solar irradiance variations in the 170-400 nm region from the Mg II index variations (Cebula *et al.*, 1992; DeLand and Cebula, 1993). Mg II index products have been derived from NOAA-9 and NOAA-11 SBUV/2 irradiance measurements using slightly different source data and algorithms (*e.g.* Cebula *et al.*, 1992; Donnelly, 1988, 1991). This paper presents a comparison of these SBUV/2 Mg II index products, and gives recommendations for further use of the data.

DATA SETS

The "classical" Mg II index proposed by Heath and Schlesinger (1986), and employed by Cebula *et al.* (1992) and DeLand and Cebula (1993), uses a total of 7 wavelength positions about the Mg II absorption feature (Figure 1). The average irradiance from 3 core wavelengths comprises the numerator of the ratio, while the irradiances from 2 pairs of wave-

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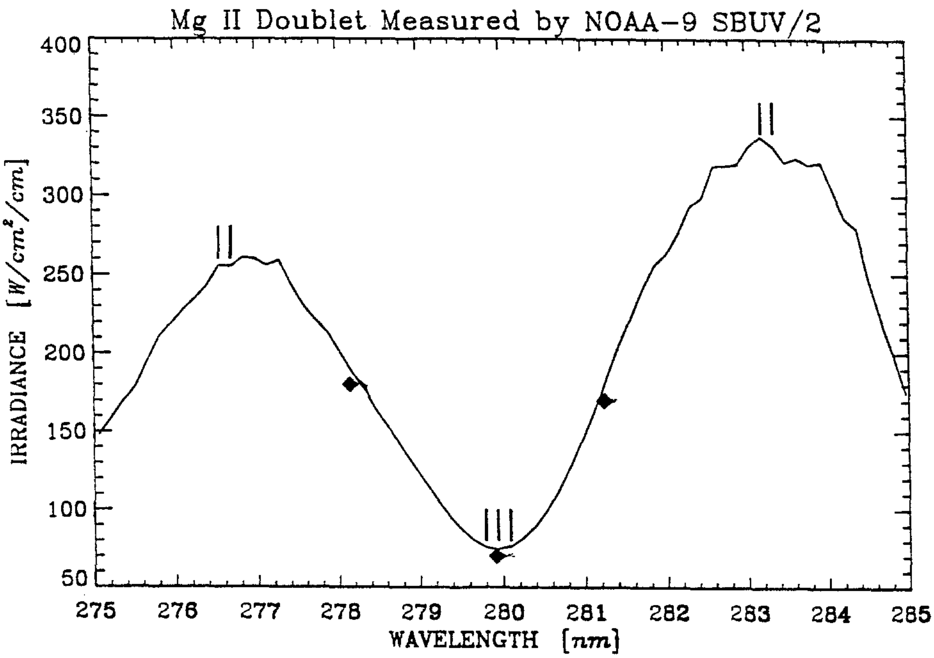

Fig. 1. The Mg II doublet at 280 nm as observed in the NOAA-9 SBUV/2 "Day 1" sweep mode spectrum. Positions of the 7 wavelengths used in the "classical" Mg II index are indicated by heavy lines, and the 3 discrete mode wavelengths used in the "modified" Mg II product are marked with diamonds. Adapted from DeLand and Cebula (1993) with permission.

lengths in the wings of the line are combined to give the denominator of the ratio. The Nimbus-7 Mg II index used irradiances taken from the daily average of three continuous scan measurements over the 160-400 nm region ("sweep mode") to construct the Mg II index. These measurements have been continued beginning in March 1985 for NOAA-9 SBUV/2 and December 1988 for NOAA-11 SBUV/2, with only 2 sweep mode scans per day available. The Mg II index products derived from these data are shown in Figures 2(*a*) and 3(*a*) respectively, and are only plotted through October 1992 for consistency with the "modified" Mg II index described below. Solar rotational modulations of up to 7% can be seen, and the solar cycle amplitude of the "classical" Mg II index is approximately 9-10% (Cebula *et al.*, 1992). No corrections have been made to the data for long-term drift of the nominal wavelength scale calibration. All data were processed with an algorithm which incorporates a full treatment of the instrument characterization (goniometry, PMT temperature dependence, interrange ratio time dependence). The interrange ratio time dependence was determined from in-flight Earth radiance measurements (*e.g.*, Laamann and Cebula, 1993).

Beginning in May 1986 for NOAA-9 and in February 1989 for NOAA-11, additional irradiance measurements of the Mg II absorption feature were begun using step scan measurements at 12 wavelength positions ("discrete mode"), which included the 7 "classical" wave-

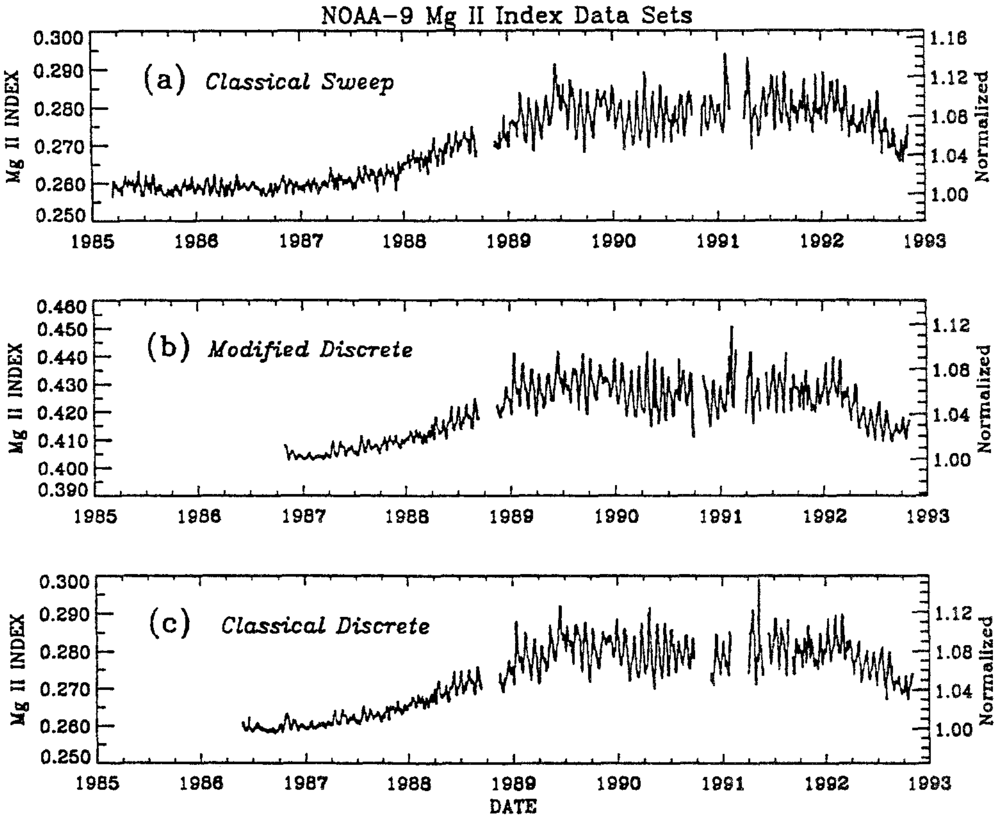

Fig. 2. Time series of NOAA-9 Mg II index products: (*a*) "classical" sweep mode; (*b*) "modified" discrete mode; (*c*) "classical" discrete mode. The sweep mode Mg II time series has been smoothed with a 5-day binomial average. The right-hand Y-axis shows the Mg II data normalized to the average of 8-12 November 1986 for each data set.

lengths and 5 more positions along the sides of the line (see Figure 1). The discrete mode irradiance measurements are inherently more precise than the sweep mode data because the sample integration time is increased by a factor of 12.5, the instrument steps and locks into each wavelength position prior to taking data, and 8-9 scans are available to construct daily average values.

Donnelly (1988, 1991) has used the NOAA-9 and NOAA-11 discrete mode measurements of the Mg II line to construct a "modified" Mg II index product using a total of three wavelengths (1 position in the core of the line, and 1 position on each side to represent the continuum). The wavelengths chosen to represent the continuum irradiance lie closer to the core of the line than the "classical" wing wavelengths in order to avoid the transition between electronic gain ranges described by Cebula *et al.* (1992), which introduces noise into the sweep mode Mg II index. The "modified" Mg II index derived by Donnelly (1988, 1991) also uses a limited instrument characterization, including a simplified correction for

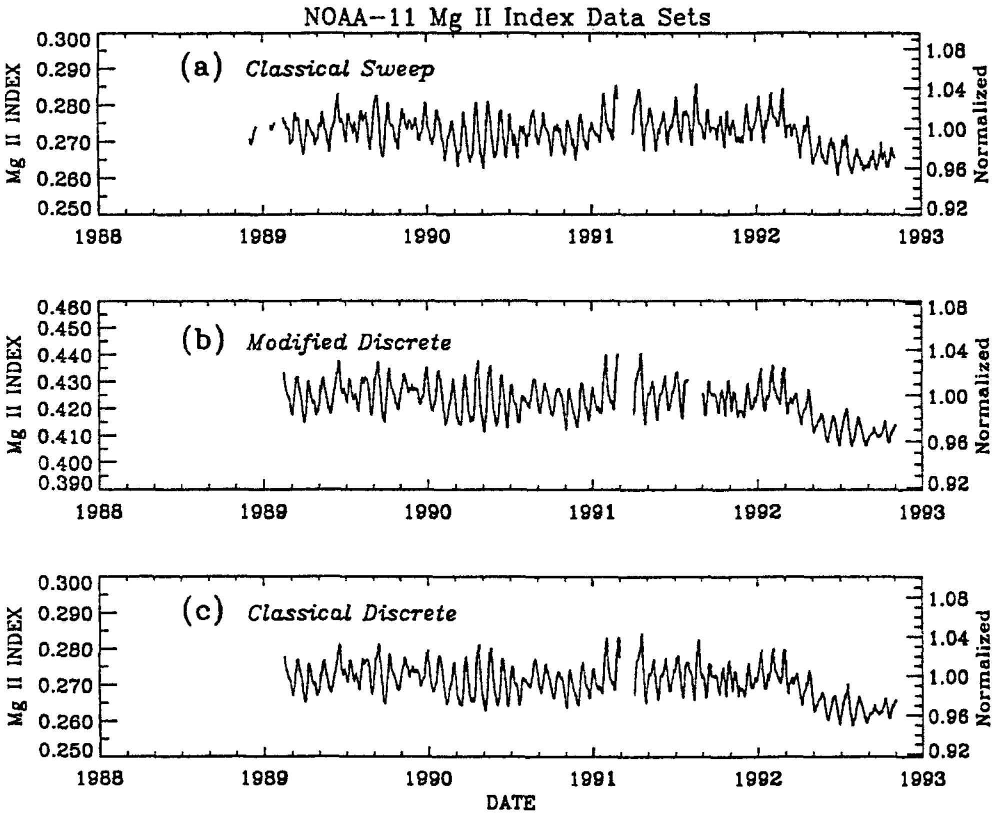

Fig. 3. Time series of NOAA-11 Mg II index products: (*a*) "classical" sweep mode; (*b*) "modified" discrete mode; (*c*) "classical" discrete mode. The sweep mode Mg II time series has been smoothed with a 5-day binomial average. The right-hand Y-axis shows the Mg II data normalized to the average of July 1989 for each data set.

goniometry (L. Puga, private communication). The "modified" Mg II index products for NOAA-9 (October 1986 to October 1992) and NOAA-11 (February 1989 to October 1992), kindly provided by R. F. Donnelly and L. C. Puga, are shown in Figures 2(*b*) and 3(*b*) respectively. The data after April 1990 are preliminary, and require further corrections before quantitative use. No correction for wavelength scale drift has been applied. The magnitude of the day-to-day noise is considerably reduced from the "classical" sweep mode Mg II index due to the improved signal-to-noise ratio in the irradiance data. The absolute magnitude of the "modified" Mg II index is greater than the "classical" Mg II index because the wing wavelengths chosen lie closer to the Mg II line core. This selection also reduces the amplitude of the solar variability signal observed by the "modified" Mg II index, because the wing wavelengths are now more responsive to chromospheric variations.

A "classical discrete" Mg II index product can also be constructed from the NOAA-9 and NOAA-11 discrete mode solar irradiance measurements, using the same algorithm and wavelengths chosen for the "classical sweep" Mg II index. These data have not been corrected for wavelength scale drift. The "classical discrete" data sets are shown in Figures 2(c) and 3(c), also plotted through October 1992 only, and have the same magnitude and response to solar variability as the "classical sweep" Mg II index to within 0.5%. However, as discussed previously, the statistical noise in the "classical discrete" product is reduced by a factor of 7 relative to the "classical sweep" product due to changes in signal integration time, wavelength selection repeatability, and number of daily scans. This gives a substantial improvement in the representation of solar variability during periods of low solar activity (compare 1986-1987 in Figures 2(*a*) and 2(*c*)).

MG II INDEX COMPARISONS

The difference in response between the "classical" and "modified" Mg II indexes to solar activity variations in the core of the Mg II line can be estimated by using the solar variability scale factors for each wavelength of DeLand and Cebula (1993). These scale factors give the solar irradiance change at each wavelength relative to the "classical" Mg II index change. Thus, if the 0.2 nm gridded scale factors of DeLand and Cebula (1993) are interpolated to the exact wavelengths used in the "classical" Mg II index, the difference between the Mg II core and Mg II wing scale factors would ideally be 1.00. The calculated result for the "classical" Mg II index is 1.03, which is within the combined 1 σ uncertainties of the scale factors. The difference between the interpolated Mg II core and wing scale factors for the "modified" Mg II index is 0.93. The decrease is caused by the larger scale factors for the wing wavelengths of the "modified" Mg II index, reflecting the increased contribution of chromospheric activity at those wavelengths relative to the "classical" wing wavelengths. This result suggests that the "classical" Mg II index response to solar chromospheric activity should be approximately 10% larger in magnitude than the "modified" Mg II index response for both short-term and long-term solar variations.

The slope of a linear regression fit between the "classical" and "modified" data sets, normalizing both to a common date to remove the effects of the absolute offset, should indicate the relative magnitude of the long-term solar variation response. The ratio of the "classical" and "modified" scale factor results corresponds to a slope of 1.11. Regression fits between the "modified" and "classical sweep" Mg II data sets give slopes of 1.13 (R = 0.864) for NOAA-9 and 1.04 (R = 0.919) for NOAA-11, while regression fits with the less noisy "classical discrete" Mg II data give slopes of 1.14 (R = 0.951) and 1.07 (R = 0.996) respectively. These values are consistent with the scale factor analysis. For the observed rise of 9-10% in the "classical" NOAA-9 Mg II index during solar cycle 21, the regression fit results suggest that the increase in the "modified" Mg II index should be approximately 1.0-1.5% less, or approximately 7.5-9% for solar cycle 21.

Comparisons have also been made between the "classical discrete" and "classical sweep" Mg II index data sets for NOAA-9 and NOAA-11. The absolute values of these two products agree to within 0.5% for both instruments, as expected due to their identical design. An indication of the increased sensitivity of the "classical discrete" Mg II index is its detection of differences of 0.3-0.6% in rotational modulation strength between the "classical discrete" and "modified" Mg II indexes for 1989-1991 NOAA-11 data, when 27-day solar variability was strong and persistent at the 3-6% level. The magnitude of the difference in short-term response, approximately 10% of the total amplitude, is consistent with the estimate derived from the scale factor analysis.

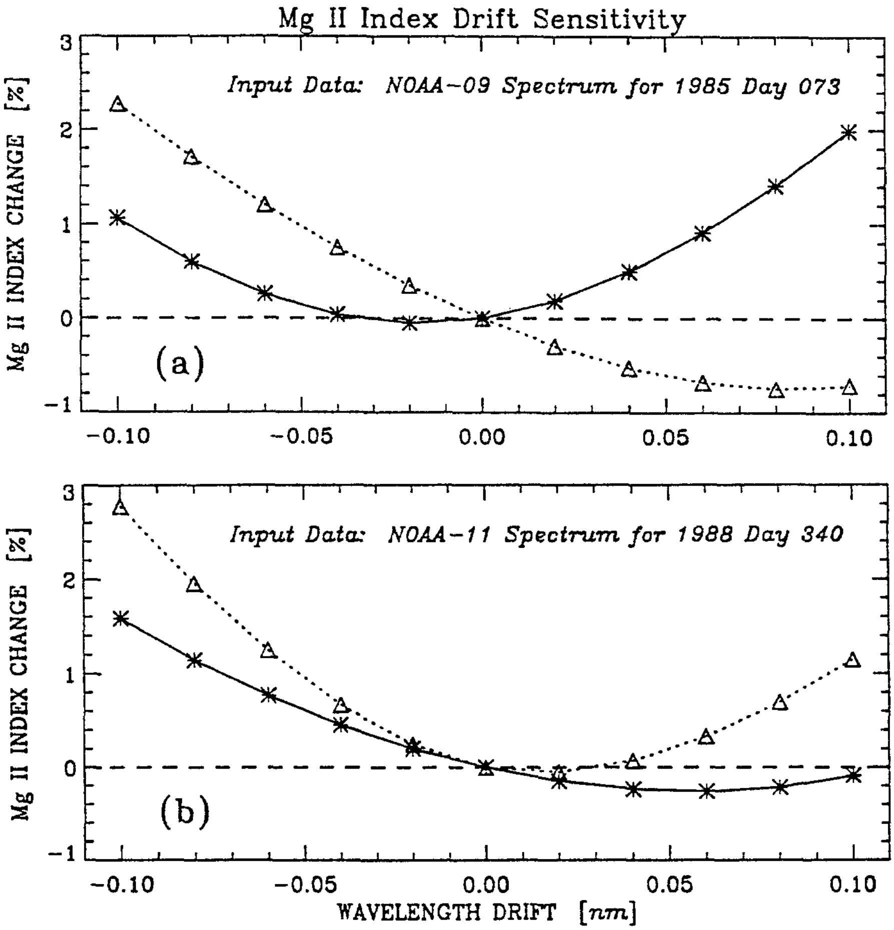

Fig. 4. (*a*) Calculated changes in the NOAA-9 Mg II index value as a function of wavelength scale drift. The stars and solid line represent the "classical" Mg II index results, the triangles and dotted line indicate the "modified" Mg II index results. (*b*) Calculated changes in the NOAA-11 Mg II index value as a function of wavelength scale drift. Identifications are as in part (*a*).

WAVELENGTH SCALE DRIFT

When a time series of the difference between the NOAA-9 "classical" and "modified" Mg II indexes is constructed, the magnitude is found to be approximately 3% by 1992, rather than the 1-1.5% predicted above. Some of this discrepancy is probably caused by the complicated thermal history of the NOAA-9 spacecraft induced by its drifting orbit (Cebula and DeLand, 1992). However, there are also changes in the Mg II index values due to wavelength scale drift with time. The wavelength scale calibration of the SBUV/2 instrument is monitored approximately bi-weekly during flight by tracking the measured positions of emission lines from an on-board mercury lamp. A similar analysis is performed with solar absorption lines using sweep mode data. Further details are given in DeLand *et al.* (1992). SBUV/2 instrument wavelength scale changes are largest for sweep mode measurements, where the data at each wavelength are integrated from a continuous scan without stopping at predetermined positions. The NOAA-9 sweep mode wavelength scale drift is estimated to be approximately $\Delta\lambda_{swp} \approx +0.10$ nm over 6 years (DeLand *et al.*, 1992), which corresponds to a change of approximately +2% in the "classical sweep" Mg II index based on the reference wavelength positions (Figure 4(*a*)).

The magnitude of SBUV/2 discrete mode wavelength scale drift is much smaller than for sweep mode data, because the instrument "steps" to each wavelength position and locks before taking data. The estimated NOAA-9 discrete mode wavelength scale change over the same period is approximately $\Delta\lambda_{dis} \approx +0.03$ nm (DeLand *et al.*, 1992). Calculations with a reference irradiance spectrum show that the "modified" and "classical" Mg II index products have similar sensitivities to wavelength scale drift for small drifts, but the "modified" Mg II index tends to be more sensitive for larger changes (Figure 4). This difference is primarily due to the use of wing wavelengths for the "modified" Mg II index located in spectral regions where the irradiance changes rapidly and unequally between the short wavelength and long wavelength sides of the Mg II line (see Figure 1). The impact of this difference in response to wavelength scale drift is approximately ΔMgII = 1% for the NOAA-9 discrete mode Mg II index products using Figure 4(*a*), proportioned roughly equally between an increase in the "classical discrete" product and a decrease in the "modified" product. For NOAA-11, the estimated wavelength scale drift of $\Delta\lambda_{dis} \leq 0.01$ nm through mid-1992 from DeLand *et al.* (1992) gives a change in Mg II index values of ΔMgII < 0.3% for both products (Figure 4(*b*)). However, the continuing drift of the NOAA-11 orbit may lead to a greater effect in the future. Because of the non-negligible impact of wavelength scale drift on the long-term response of the Mg II index, it is clear that <u>each</u> current Mg II product must be corrected for this effect.

CONCLUSIONS

The Mg II index has been shown to provide a good proxy of solar UV variability on both short and long time scales. Two versions of the Mg II index have been constructed and published from the NOAA-9 and NOAA-11 SBUV/2 data. The "classical" Mg II index constructed from sweep mode data is consistent with the first Mg II index product from Nimbus-7 SBUV, but is significantly affected by noise as a result of the SBUV/2 instrument design. The "modified" Mg II index reduces the noise through the use of discrete mode data and different wavelength selection. This choice of wavelengths also reduces the sensitivity of the "modified" Mg II index to solar variations, and increases the potential impact of long-term wavelength scale drift. Both current Mg II products must be corrected for the effects of wavelength scale drift to improve their value as a long-term solar UV proxy.

The most appropriate SBUV/2 Mg II index product for future use would seem to be a combination of these two products, namely the "classical discrete" Mg II index as shown in Figures 2(*c*) and 3(*c*). We feel that our experience with characterization of the SBUV/2 instruments allows us to understand and correct for effects such as time-dependent gain range ratio and wavelength scale changes. The "classical discrete" Mg II index combines the improved quality of the discrete-mode data with the historical precedent and lesser sensitivity to wavelength scale drift of the "classical" set of wavelengths. We suggest that future "composite" Mg II index products which link together Mg II index data sets from different instruments (*e.g.* Donnelly (1991), DeLand and Cebula (1993)) use the "classical discrete" Mg II index product for SBUV/2 data.

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